# THE EFFECT OF LIGHT INTENSITY ON PREDATION OF SOCKEYE SALMON FRY BY COTTIDS IN THE CEDAR RIVER

Roger Tabor
U.S. Fish and Wildlife Service
Western Washington Office
Fisheries and Watershed Assessment Division
Lacey, Washington

Gayle Brown<sup>1</sup>
U.S. Geological Survey
Western Fisheries Science Center
6505 NE 65<sup>th</sup> Street
Seattle, Washington 98115

and

Aaron Hird and Stephen Hager
U.S. Fish and Wildlife Service
Western Washington Office
Fisheries and Watershed Assessment Division
Lacey, Washington

April 2001

<sup>1</sup>Present address: Fisheries and Oceans Canada - Coastal BC South, Nanaimo, British Columbia

#### **ABSTRACT**

In the Cedar River, we examined the relationship between light intensity level and migratory behavior of sockeye salmon fry (*Oncorhynchus nerka*) and predation by cottids. Additionally, light intensity readings were taken to document the location of high artificial light intensity levels and determine what atmospheric conditions affect those light levels. The effect of light intensity on sockeye salmon fry was examined with two methods: 1) comparison of lighted and non-lighted areas in the City of Renton; and, 2) experimental trials with standardized amounts of light added to the river.

Within the lower 2.9 kilometers of the Cedar River, there were several locations with high light intensity levels. Most were next to street bridges. The highest light readings recorded were at the I-405 Bridge and the Renton Library. In the lower Cedar River, artificial lighting appeared to come from two major sources: direct lighting and reflected lighting off of the clouds. At locations with minimal direct lighting, the highest light intensity levels occurred on overcast nights due to reflected light. The lowest levels occurred during clear, moonless nights. As far upstream as river

kilometer 9.8, we recorded readings during overcast nights that were higher than during a clear night with a full moon.

Experimental trials were done at two locations away from any lights, Lion's Club Park and Elliot Park. Two trials were done at the Lion's Club Park, both following a release of hatchery sockeye salmon fry. Most trials at Elliot Park were conducted below a sockeye salmon spawning channel. At the Lion's Club Park, light intensity treatments were done in two habitat types, gravel shore and rip-rap shore.

At all City of Renton sites examined, the abundance of sockeye salmon fry was substantially higher at sites with high light intensity levels than at nearby sites with low light. Correspondingly, most predation of fry by cottids was observed in the bright light areas. Higher predation rates were observed along the shoreline as well as in the mid-channel area. In relation to other sampling conducted by the U.S. Fish and Wildlife Service, the I-405 Bridge lighted area was the only location we have ever seen any significant predation of fry by cottids in a mid-channel area of a riffle in the Cedar River.

In the experimental trials, we found that the abundance of fry and predation by cottids was related to light intensity levels. In one bright light treatment, we were able to slow the migratory behavior of over 550 sockeye salmon fry within an 8-meter (m) shoreline section. At the Lion's Club Park, gravel shores had five times as many fry as rip-rap shores for a given light intensity level. Gravel shores had a larger low-velocity area than did rip-rap shores. In two experimental trials, we also examined the abundance of fry shortly after the lights were turned off. In all lighted experimental units, the number of fry declined dramatically after the lights were turned off, however, in control units (no light added), the number of fry remained about the same or actually increased slightly. In the experimental trials, we also monitored the abundance of juvenile chinook salmon

(O. tshawytscha). Small numbers of chinook were observed. No relationship between chinook salmon abundance and light intensity was detected. In conclusion, our results indicated that any estimation of predation loss needs to assess the light intensity level, as well as fry abundance and shoreline and mid-channel habitat.

# TABLE OF CONTENTS

	<u>Page</u>
Abstract	ii
List of Figures	v
Introduction	1
Study Site	1
Methods	1
Results	4
Discussion	8
Acknowledgments	11
References	12

# LIST OF FIGURES

<u>Figure</u>	·	<u>Page</u>
1	Map of lower Cedar River and location of study sites	14
2	Fry abundance and predation rates (fry/stomach) for three Cedar River sites in Renton, Washington	15
3	Sockeye salmon fry abundance (log scale) at three light intensity levels while lights were on and then turned off for two experimental trials in the Cedar River	16
4	Sockeye salmon fry abundance and cottid predation of fry at three light intensity levels and two habitat types from March 31, 1999 experimental trial at Lion's Club Park (Rkm 18.3) on the Cedar River	17
5	Sockeye salmon fry abundance and cottid predation of fry at four light intensity levels and two habitat types from April 5, 1999 experimental trial at Lion's Club Park (Rkm 18.3) on the Cedar River	18
6	Sockeye salmon fry abundance and cottid predation of fry at three light intensity levels and three channel types from April 7, 1999 experimental trial at Elliot Park (Rkm 7.4) on the Cedar River	19
7	Sockeye salmon fry abundance (log scale) and cottid predation of fry at three light intensity levels from five nights at the Elliot Park side channel (just below the spawning channel)	20
8	Chinook salmon fry abundance at Lion's Club Park and Elliot Park at various light intensity levels	21
9	Light intensity readings (lumens/ft²; log scale) during an overcast night (solid line, solid squares) and a clear, moonless night (dashed line, open circles) from the lower 2.9 kilometers of the Cedar River	22
10	Light intensity readings (+/- range, vertical line) at three Cedar River locations that have little or no direct artificial lighting	. 23

#### INTRODUCTION

After emerging from their redds, most sockeye salmon (*Oncorhynchus nerka*) fry immediately emigrate downstream to a lake environment where they reside for the next year. They reduce their vulnerability to predators by emigrating at night. Results of recent lab experiments indicated that increased light appears to slow or stop emigration of sockeye salmon fry which makes them more vulnerable to capture by predators (Tabor et al. 1998a). The Lake Washington sockeye salmon occur within a large urban area. In some river sections that sockeye salmon fry must migrate through, artificial lighting is present. As part of the mitigation for the recent flood control project, light intensity levels were reduced or proposed to be reduced in some areas of the lower Cedar River to reduce predation. Although reduced lighting appears to benefit sockeye salmon fry, little work has been done to quantify its effect on predation in a field situation. Most earlier work was done under laboratory conditions and results can be difficult to apply to field conditions. In 1998 and 1999, we attempted to quantify the effects of increased light under field conditions in the Cedar River. In 2000, we also took light intensity readings in the lower Cedar River to identify areas with high artificial light levels.

## **STUDY SITE**

The Cedar River is the main tributary for the Lake Washington basin. The lower 35.1 kilometers are accessible to anadromous salmonids. Landsburg Dam (Figure 1), a water diversion structure, prevents fish from migrating further upstream. The Cedar River is the major spawning area for a large population of sockeye salmon. Runs in excess of 300,000 fish have occurred in some years.

The lower 3 kilometers of the Cedar River occurs within a large flood plain that was the historical Black River flood plain and Lake Washington delta. Presently, the area is the City of Renton (Figure 1) and has numerous artificial light sources due to urban and residential development. Upstream of river kilometer (Rkm) 3, the river is confined in a relatively narrow canyon with some residential development but substantially less artificial light than the Renton area.

## **METHODS**

We examined the effect of light intensity on sockeye salmon fry with two methods: 1) comparison of lighted and non-lighted areas in the City of Renton; and, 2) experimental trials with standardized amounts of light added to the river. Additionally, we took light intensity readings in the lower Cedar River to document light levels. All light intensity measurements were made with an International Light Inc. model IL1400A radiometer/photometer. Light intensity was measured as lumens/ft².

### PREDATION AND SALMONID FRY BEHAVIOR

## Renton City lights

Four sites were selected in Renton; 1) I-405 Bridge (Rkm 2.7), 2) Renton Library (Rkm 2.5) Williams Avenue Bridge (Rkm 2.0), and South Boeing Bridge (Rkm 1.2). Each had a high light intensity area and a nearby area with similar habitat and substantially lower light intensity levels. Two sites were done in 1998 and the other two were done in 1999. Fry abundance was estimated at each site except the South Boeing Bridge. In 1998, we used a small 2.5-m long by 1-m high beach seine to compare fry abundance. Fry at the 1999 sites were counted by slowly moving along the shoreline using a flashlight. To be consistent between treatments, we only counted fry within the beam of the flashlight. We assumed that the counting had a minimal effect on fry abundance because it was done within a short period of time, approximately 1 minute per shoreline section. Sockeye salmon fry as well as chinook salmon fry (O. tshawytscha) were counted. The two species could be easily distinguished based on parr marks and relative size. Chinook salmon fry were considerably larger than sockeye salmon fry. Light intensity measurements (lumens/ft²) were taken at the surface of the water in the middle of the area sampled. At three of the four sites, cottids were collected for stomach analysis to compare predation rates. Fish were collected with backpack electrofishing equipment. Cottids were collected along the shoreline and/or in the mid-channel area. Cottids along the shoreline were collected visually with the aid of dip nets. Cottids in the midchannel area were collected passively with the aid of block nets. After capture, cottids were identified to species and total length (TL) was measured. Afterwards, their stomachs were flushed and salmonid fry were counted. We sampled cottids that were > 49 millimeters (mm) TL. Smaller cottids rarely consume sockeye salmon fry. We assumed that cottids had captured fry in the same general area that they were captured. A Mann-Whitney U test was used to compare differences in predation rates between a lighted site and the control site. Data were log-transformed because the data was multiplicative rather than additive (Zar 1984).

## **Experimental Trials**

Experimental trials were done at two sites in 1999, the Lion's Club Park at Rkm 18.3 and the Elliot Park at Rkm 7.4 (Figure 1). Sites were divided into shoreline sections that had uniform habitat. Two experimental trials were conducted at the Lion's Club Park along a 112-m shoreline section. The upper 56 m had a rip-rap shoreline while the lower 56 m was a gravel shoreline. Both trials were conducted on a night when hatchery sockeye salmon fry were released upstream at Rkm 21.7. On March 31, 1999, 135,000 fry were released, and on April 5, 1999, 57,000 fry were released. The other site at the Elliot Park consisted of three 40-m shoreline sections: 1) main channel, 2) braided channel; and, 3) side channel at the outlet to the spawning channel. Within each section, three experimental light intensity levels were tested. The main channel and braided channel section were only done once due to the low numbers of fry. The side channel was done five times because good numbers of fry were migrating through this section during the study period. Most of the fry in this section were probably migrants from a nearby spawning channel.

Each shoreline section was divided into 8-m long units. Lights were only added to every other unit to insure light from one experimental unit did not affect another one. Treatments were randomly assigned within each shoreline section. Two lights were used for each experimental unit. Lights were mounted at the top of a 2-m pole, placed 1 m from both edges of each unit, and lights were directed towards the middle of the unit. An individual light system consisted of a 60-watt light bulb, a deflector to focus the light, and a dimmer switch to control the light intensity. We used five light intensity levels: 1) control (no lights): 0.0006-0.010; 2) dim: 0.015-0.025; 3) low: 0.045-0.055; 4) medium: 0.10-0.14; and, 5) bright: 1.0-1.4 lumens/ft².

Light intensity measurements were taken at the surface, 2 meters from shore. Generally three measurements were taken, one in the middle and one each from just inside of the upstream and downstream edges. The middle of each experimental unit was the brightest and the upstream and downstream edges were the dimmest. Light intensity was slowly attenuated across the river channel. Lights were turned on shortly after dusk and adjusted to get the appropriate light intensity. Fry were counted with a flashlight, similar to the City of Renton sites. For some experimental trials, we turned off the lights and recounted the number of fry 20 minutes later.

In most experimental trials, we used backpack electrofishing equipment to collect cottids to determine the predation rate. After capture, cottid stomachs were flushed and the number of ingested fry was counted. Fry were categorized as freshly ingested or well digested. Only counts of freshly ingested fry were used. We assumed that freshly ingested fry were consumed during the experiment and well digested fry were consumed the prior night or sometime before the experiment. Since we started the experiments shortly after sunset and cottids are primarily nocturnal, we felt this was a valid assumption.

Differences in fry abundance were tested with a two-way analysis of variance (ANOVA) without replication. A Mann-Whitney U test (two samples) or a Kruskal-Wallis test (more than two samples) was used to compare differences in predation rates. Data were log-transformed because the data was multiplicative rather than additive (Zar 1984).

## LIGHT INTENSITY READINGS

Readings of light intensity in the lower Cedar River were done under three scenarios: 1) overcast skies; 2) clear skies, no moon; and, 3) clear skies, full moon. Light reading were taken every 50 m from Rkm 0.9 to 2.9. Below Rkm 0.9 access to the river was limited in many areas. However, additional readings were done at Rkm 0.0, 0.2, 0.3, and 0.7. We also included one site at Rkm 9.8. Additional readings were also taken at major light sources to determine peak light levels. For safety reasons, light readings were taken close to the river bank, approximately 1-5 m from shore. In most locations, the mid-river light reading would be lower than readings taken close to shore because the light source is located on the river bank. At some locations, such as I-405 Bridge and Renton Library, light sources span the entire channel width. At a few sites, we took light readings on the opposite bank from the light source. All readings were taken at the surface of the water. Most readings were taken from the right bank except between the Renton Library (Rkm 2.5) and Houser Way Bridge (Rkm 2.6), where the right bank was difficult to access.

#### RESULTS

## **SOCKEYE SALMON FRY**

## Renton City Lights

Fry abundance. At all three sites examined, the abundance of sockeye salmon fry was substantially higher at sites with high light intensity levels than at a nearby site with low light (Figure 2). This was particularly apparent at the I-405 site where large numbers of fry were present under the bridge but 180 m upstream we were unable to collect a single fry. Both sites had a large amount of shallow, low velocity water where numerous fry could reside. In contrast, few sockeye salmon fry were observed at the Renton Library. Light levels were lower and there was little shallow, low velocity water along the shoreline. However, all sockeye salmon fry observed were present in the lighted area (Figure 2). The Williams Bridge site was counted on two nights, both having similar results. Most fry were nearest the bridge where the light intensity levels were the highest. At 35 m from the bridge, light levels were greatly reduced (0.012 lumens/ft²) and only a couple of fry were observed (Figure 2).

Predation. At both the I-405 Bridge and Renton Library, little predation was observed in control areas with little light, while relatively high predation rates were observed in lighted areas (Figure 2). Fifty-three percent of the cottids in the mid-channel area of the lighted I-405 site had consumed fry (0.9 fry/stomach), while no predation occurred at the control. Predation rates were significantly higher in the lighted area (Mann-Whitney U test = 58.5; P = 0.002). Preliminary sampling was also done on February 23, 1998, at the I-405 Bridge (the control was not sampled). From 15 cottids collected, a total of 18 sockeye salmon fry were present in the stomach samples (1.2 fry/stomach). At the Renton Library site, cottids were sampled at both the shoreline and midchannel areas on the same night (March 18, 1999). In the control, no predation was observed in the shoreline area and 1 sockeye salmon fry was observed out of 18 stomach samples from the midchannel. In the lighted shoreline area, 33% of the cottids had consumed fry (0.6 fry/stomach) but no predation was observed in the lighted mid-channel area (Figure 2). Predation rates were significantly higher in the shoreline of the lighted area than the control area (Mann-Whitney U test = 63; P = 0.03). Of the cottids (> 49 mm TL) collected at both sites, 95% were coastrange sculpin (Cottus aleuticus) and 5% were torrent sculpin (C. rhotheus). Predation was observed in both cottid species.

At the South Boeing Bridge site (including control), we collected 105 cottids but only three were > 49 mm TL. No fry was observed in their stomachs. We also flushed the stomachs of four cottids that were 45-49 mm TL. Of these, one torrent sculpin (47 mm TL) that was collected at the bridge had consumed a sockeye salmon fry. No predation was observed at the control site. Light intensity at the South Boeing Bridge was 0.28 lumens/ft² and 0.12 lumens/ft² at the control.

## **Experimental Trials**

Fry abundance. At Lion's Club Park on March 31 (Figure 3) and April 5, few sockeye salmon fry were observed in all units for the first 45 to 60 minutes. However, within the next 20 minutes the number of fry increased dramatically. For example, in the bright-light experimental unit, the number of fry changed from 27 at 2025 hours, to 577 at 2045 hours. The increase in the number of fry was due to the large number of hatchery fish that had been released earlier that evening. The fry were released at Rkm 21.7 at approximately 2008 hours (90 minutes after sunset). Experimental units with higher light levels had significantly more fry in both experimental trials (ANOVA; March 31, P = 0.02; April 5, P = 0.005; Figures 4,5). Within each light intensity level, higher numbers of fry occurred in the gravel shore than the rip-rap shore (ANOVA; March 31, P = 0.04; April 5, P = 0.03; Figures 4,5). On average, gravel shores had five times as many fry as rip-rap shores for a given light intensity level.

Overall, fry abundance results at Elliot Park followed similar patterns as at Lion's Club Park. On April 7, low numbers of fry were observed in every experimental unit. However, the highest numbers of fry occurred in the units with the highest light levels for each channel type (Figure 6). Analysis of variance revealed a significant difference (P = 0.003) in fry abundance between light intensity levels. Fry abundance was done on four additional dates in the side channel, however, on May 3, the light system for the medium-light experimental unit malfunctioned, thus we were unable to get a count for that experimental unit (Figure 7). Between the fives dates that the side channel was sampled, the abundance of fry varied greatly. Most fry were probably migrants from the spawning channel. Peak outmigration appeared to be around May 3. Analysis of variance revealed a significant difference (P < 0.001) in fry abundance between light intensity levels. The highest number of fry was always in the medium light unit (Figure 7). On every date, the dim light unit had more fry than the control unit.

In two experimental trials, we also examined the abundance of fry shortly after the lights were turned off. In all lighted experimental units, the number of fry declined dramatically after the lights were turned off (Figure 3). In control units (no light added), the number of fry remained about the same or actually increased slightly (Figure 3).

Predation. In general, predation rates of cottids showed the same trend as fry abundance. The highest predation rates recorded were from experimental units with increased light. This trend was particularly noticeable during the March 31 trial at the Lion's Club Park. No predation was detected in the control units. In contrast, large numbers of fry were found in the stomach samples of cottids collected from the bright-light experimental unit (Figure 4). Three torrent sculpin were collected from this unit with 10 or more fry in their stomachs. The maximum number of sockeye salmon fry consumed by an individual fish was 13 (92 mm TL, torrent sculpin). Differences in predation rates were marginally significant (Kruskal-Wallis test = 5.7, P = 0.058) between experimental units but not significant between medium and bright experimental units (Mann-Whitney U test = 3.5, P = 0.23). Predation rates in both lighted rip-rap experimental units were

lower than in units with gravel shores. Differences were significant between the two bright experimental units (Mann-Whitney U test = 8.0, P = 0.03) but not the medium light experimental unit (Mann-Whitney U test = 3.5, P = 0.66).

Predation rates on April 5 were low for all experimental units. Only three out of 42 cottids had consumed sockeye salmon fry. No differences between treatments were detected. However, four of the five fry consumed were from the medium-light experimental units and no predation was observed in the control units (Figure 5).

On April 5, one riffle sculpin (89 mm TL; *C. gulosus*) was collected with 14 yolk-sac sockeye salmon fry. Because these fish were yolk-sac fry, we assumed these were not migrating fish but instead they probably were captured in the substrate. Additionally, many were well-digested and thus were not consumed on the night of our experiment. None of these fry were included in our estimate of predation. Some sculpins such as reticulate sculpin (*C. perplexus*), have been shown to be able to move into the substrate to consume recently-hatched salmonid fry (Phillips and Claire 1966). Additionally, we have collected several riffle sculpin that consumed yolk-sac fry in another location of the Cedar River (R. Tabor, unpublished data).

During the April 7 experimental trial, few predators were collected along the shore in the main channel and braided channel. However, 23 cottids were collected in the side channel. The only experimental unit to have any predation of fry was the medium-light unit. In addition to April 7, side channel predators were sampled two other times. In each trial, the highest predation rates were observed in the medium-light unit; however, there was no significant differences detected between the light intensity levels.

At Lion's Club Park, torrent sculpin made up 91% of the cottids captured, while riffle sculpin made 8% and shorthead sculpin 1% (*C. confusus*). No coastrange sculpin were observed at this site. In the side channel at Elliot Park, 50% of the cottids were torrent sculpin, 26% coastrange sculpin and 24% riffle sculpin.

In addition to cottids, we also collected a few salmonids. The number and species collected included five juvenile coho salmon (*O. kisutch;* range, 74-112 mm FL), eight unidentified trout (range 76-103 mm FL), one cutthroat trout (*O. clarki;* 160 mm FL), and one rainbow trout (*O. mykiss;* 146 mm FL). Almost all were collected at the Lion's Club Park site. The only salmonids observed to have freshly-ingested fry in their stomachs were three juvenile coho salmon. One juvenile coho salmon (109 mm FL) was collected with five freshly ingested sockeye salmon fry. The fish was captured in the bright experimental unit on March 31, 1999. The other two juvenile coho salmon had one fry each in their stomachs. These fish were collected from experimental units with dim and low light intensity levels. Therefore, salmonid predation rates show the same general trend as with cottids but because the sample sizes are small it is difficult to say anything conclusive. Additionally, salmonids are far more mobile than cottids and thus there is a greater chance that they may have consumed their prey at a different location. However, most of the salmonids collected were small and thus, may have a small home range.

## **CHINOOK SALMON FRY**

Small numbers of chinook salmon fry were also observed along the shoreline. There was no apparent pattern between different light intensity levels (Figure 8). In some cases, chinook salmon were more abundant in treatments with little or no light. For example, at the I-405 bridge site, we collected 3.4 chinook salmon/seine in the control area but only 0.3 chinook salmon/seine in the lighted area. Only one chinook salmon was seen from all the cottid stomachs examined. The cottid was a riffle sculpin (95 mm TL) captured in the bright section at the Lion's Club Park during the March 31 experiment.

## LIGHT INTENSITY READINGS

Most high light intensity sites were next to street bridges (Figure 9). The Renton Library and a Boeing building at Rkm 1.6 also had high light readings. The highest light readings were at the I-405 Bridge and the Renton Library. Some light sources are typically shut off during the night. The Renton Library closes at 2100 hours. Peak light levels changed from 1.90 to 0.05 lumens/ft². Many of the lights along the Cedar River Trail are turned off at 2300 hours. Most of our readings were taken while the lights were still on.

Near strong light sources, such as street lights near bridges, light intensity levels did not appear do vary greatly between different sky conditions because the artificial lights were far more intense than other lighting sources such as the moon. However, away from these lights, light intensity levels appear to vary greatly depending on cloud cover and the moon. For example, at locations close to the City of Renton, overcast nights had higher light readings than during a full moon. Reflected light off of the clouds from nearby urban areas appears to be the main light source during overcast nights. The lowest readings were during a clear, moonless night.

We examined past readings of light intensity at Rkm 0.3. In addition to readings taken in 2000, readings were also taken in 1997 and 1999. The highest light intensity readings were recorded on overcast nights (Figure 10). Light readings as high as 0.040 lumens/ft² were recorded on an overcast night, whereas during clear, moonless nights readings ranged from 0.003-0.005 lumens/ft². Even at upstream locations, reflected light appears to be a major source of lighting. At Rkm 9.8, we detected little or no light on a clear, moonless night, on a full moon night light intensity was 0.008, and on an overcast night it was 0.012 lumens/ft² (Figure 10). Upstream of Rkm 10, we did not take any light readings, but we expect that the amount of reflected light would be substantially less due to the lower amount of urban development. In this area, the highest light intensity readings would probably occur during nights with a full moon.

Light intensity readings at Rkm 0.3 were quite variable between overcast nights (Figure 10). Most likely, the thickness of the clouds and the level of the clouds influence to amount of light that is reflected. On March 27, 2000, the clouds appeared to be very thick and low. Light intensity levels on that night were the highest that we have observed.

## **DISCUSSION**

## SOCKEYE SALMON FRY BEHAVIOR

Results for field observations in Renton and field experiments corroborated results from earlier lab experiments. Increasing light intensity levels have a profound effect on the behavior of sockeye salmon fry. Fry appear to move out of the thalweg and move to low velocity water where they are vulnerable to predators such as cottids. Even small increases in light intensity levels appeared to affect fry behavior. For example, at the Elliot Park side channel we observed differences in fry abundance consistently between the control (0.010 lumens/ft²) and the dim light experiment unit (0.020 lumens/ft²). Our results suggest that any reductions in light level can be beneficial and the impact of lighting should be considered for any future development project.

We were surprised by the large number (> 550 fry) of sockeye salmon fry that were present within the bright-light experimental unit (sand/gravel shoreline) during the March 31 experiment. Approximately 120,000 fry were released on that date. Assuming a similar per kilometer survival rate as hatchery releases from Landsburg Dam (Seiler and Kishimoto 1997), we estimate that 110,000 fry moved past our experimental site (assumes that the number of wild fry was minimal). Therefore, we were able to delay 0.5% of the release group within a 8 m shoreline section with two small lights. This suggests that several large lights spread out over a long section of shoreline and across the channel with sand/gravel substrate and a low sloping bank could have a strong effect on the behavior and survival of the entire run of out-migrating fry. McDonald (1960) was able to experimentally stop the nightly movement of sockeye salmon fry with artificial lighting of 3.0 lumens/ft², however, other levels of light intensity levels were not tested. Our bright-light experimental unit was 1.0 - 1.4 lumens/ft².

Experiments at the Lion's Club Park demonstrated that habitat can have an important effect on the number of sockeye salmon fry attracted to the lights. The effect was probably due in part to the amount of low velocity habitat as well as to substrate size. Light causes sockeye salmon fry to move to low velocity areas. The rip-rap banks were steeper and had a narrower area of low velocity water than did the gravel shoreline. Differences in substrate size between the two habitat types may also have resulted in differences in predator abundance, which could influence the number of sockeye salmon fry. Typically, the number of large cottids is higher in larger substrates than smaller substrates (Tabor et al. 1999b). Other predators such as rainbow trout were probably higher near the rip-rap. The presence of predators has also been shown to increase the downstream movement of sockeye salmon fry (Ginetz and Larkin 1976; Tabor et al. 1998a) and brown trout fry (*S. trutta*; Gaudin and Caillere 1985; Bardonnet and Heland 1994).

In all of our experimental trials, we only examined the abundance and predation of fry along the shoreline. Results indicate that lights cause fry to delay their migration and move to the shoreline to an area of low velocity. Another area of low velocity water is typically very close to the substrate across the entire channel. Results from the I-405 bridge site suggest that fry move to the shore as well as move to the substrate in mid-channel areas. The I-405 bridge site has strong lights all the way across the channel. Although, we have never directly observed sockeye salmon

fry close to the substrate in the mid-channel, we did observe much higher predation rates than in similar areas with little or no light. Following 1998 and 1999 hatchery releases, we sampled a total of 10 mid-channel sites with little or no light. Out of 109 cottid stomachs examined, only one salmonid fry was seen. At the I-405 bridge site, a total of 33 fry were observed from 33 cottid stomach samples.

The use of the mid-channel substrates in lighted areas by sockeye salmon fry may be more common in areas with boulders and cobble than areas with smaller substrates. Larger substrates will create a more roughened river channel and have low velocity locations for sockeye salmon fry. Unfortunately these same sites will probably have a higher abundance of cottids > 49 mm TL. At South Boeing Bridge, the substrate was mostly small gravel and few cottids > 49 mm TL were collected and those that were > 49 mm TL were much smaller than those from the I-405 bridge which had some cobble and large gravel. Little predation was documented at the South Boeing Bridge. In the Cedar River, the number of cottids > 49 mm TL was shown to be related to the substrate size (Tabor et al. 1998b).

An important factor that probably affects the impact of artificial lighting is streamflow. The survival of hatchery sockeye salmon fry has been shown to be profoundly affected by streamflow conditions (Seiler and Kishimoto 1997). At lower flows, fry migration time is increased (Seiler and Kishimoto 1996) and they become more vulnerable to predators (Tabor et al. 1998). Fry typically migrate in the thalweg or the fastest part of the channel. During low streamflow conditions, midchannel velocities are reduced and fry will move through a lighted area slower and thus they may be more likely to be influenced by light. In fact, at streamflow levels over 1,500 cubic feet per second (cfs), approximately 10% of the sockeye salmon fry will migrate during the day (Seiler and Kishimoto 1997). Streamflow levels at Renton for the March 31 and April 5 experiments were 800 and 670 cfs, respectively (USGS, unpublished data). Base streamflow levels are 375 cfs during the fry outmigration period. Thus, we would predict that at lower streamflows more fry would be delayed in our experimental units.

Turbidity will have a large effect on light intensity levels in the water column. Light will not penetrate as well during turbid conditions. Turbidity is often related to streamflow, particularly after rain events. Fry may migrate faster during turbid conditions and visual predators such as trout will have reduced foraging success (Barrett et al. 1992; Vinyard and Yuan 1996).

## **PREDATION**

The size of the experimental units (8 m shoreline length) appeared to work well for detecting differences in fry abundance, but it may have been too small for estimating predation rates. We were able to detect differences between lighted areas and control areas but we were often unable to detect differences between light intensity levels. Few or no predators were collected in some experimental units. Also, the diets of cottids can vary between individual fish. Even when fry are abundant, many cottids will not consume them. Each site will have a variety of other prey types such as aquatic insects or oligochaetes. Also, many of the male cottids may be guarding egg nests and probably will not be actively searching for prey. In most areas, a 20-30 m shoreline would

probably be adequate to collect enough cottids to get an accurate estimate of predation. Additionally, our experiments only lasted for a few hours. Had we extended the experiments over the entire night we may have seen more predation and thus better able to detect differences between treatments. Similarly, for City of Renton light comparisons, large numbers of cottids may be needed to detect differences between light levels.

Based on earlier lab experiments, increased light levels have a profound effect on the behavior of sockeye salmon fry (Tabor et al. 1998a), however, the effect on predator behavior is not well understood. In the Cedar River, cottids appear to exhibit a functional response due to an increase in the abundance of fry but we did not observe any type of numerical response. However, our experiments were done over a short period of time and a numerical response may take several days or weeks. In Lake Iliamna, cottids exhibited a strong numerical response in relation to the abundance of sockeye salmon eggs but cottid movements to the spawning sites takes place over a period of three weeks (Foote and Brown 1998). Therefore, cottids may exhibit a numerical response to an increase in fry availability near permanent light structures. However, there are several alternative prey types in the Cedar River and cottids may not show a strong numerical response such as in Lake Iliamna, which is an oligotrophic system and alternative prey may be limited. Additionally, cottids may naturally avoid lighted areas because they may become more vulnerable to predators. Movement into lighted areas may be a tradeoff for cottids and thus they must balance increased predation risk with increased prey availability.

Cottids are generally considered nocturnal fish; they appear to hide during the day and move out from cover at night to feed. The distance they move away from their daytime cover and the relationship to light levels is not known. If they only move a short distance on a given night then the only cottids that can take advantage of the increase in fry abundance are those that have nearby cover. The number of cottids > 49 mm TL increases as the substrate size is increased (Tabor et al. 1998b). Therefore, in sand or gravel areas where fry may be abundant, cottids may have low abundance.

## CHINOOK SALMON FRY

Like sockeye salmon, many chinook salmon out-migrate to the lake as fry (D. Seiler, WDFW, unpublished data), however, while sockeye salmon fry typically use the river channel only as a migratory corridor, chinook salmon fry and juveniles may inhabit the shoreline habitat for an extended period of time (R. Peters, U.S. Fish and Wildlife Service, unpublished data). Chinook salmon may avoid lighted areas while they are inhabiting the shoreline but may become more vulnerable to predation as they move downstream through lighted areas. Nevertheless, given the low number of chinook salmon fry observed, it is problematic to make any conclusions concerning the effect of lights on chinook salmon. Further work directed at chinook salmon is needed to reach any conclusions.

## LIGHT INTENSITY READINGS

The location with the most potential for predation appeared to be the area between the I-405

Bridge and the Renton Library. The highest light levels were recorded in this area. There was also good pool habitat where fry could be consumed by large trout as well as cottids. Additionally, the mid-channel substrate is composed of cobble and gravel which was inhabited by cottids > 49 mm TL. Downstream of the Renton Library between Rkm 2.5 and 0.9 there was little pool habitat and the mid-channel substrate was predominantly gravel. Cottids may be abundant but few are > 49 mm TL.

In the lower Cedar River, artificial lighting appears to come from two major sources; direct lighting and reflected lighting off of the clouds. Direct lighting is intense lighting that occurs in a relatively small area and occurs every night and usually all night. Whereas, reflected light is not very intense but spread out over a much larger area and varies greatly with the weather. Direct lighting probably have strong localized effects on sockeye salmon fry and reflected lighting probably has weak effects over a large area. Which has more overall effect of sockeye salmon fry is difficult to assess. However, reducing direct lighting is much easier to address than reducing reflected light. Direct lighting can be turned off, redirected, or perhaps shielded (such as by trees). Reducing reflected light would be a much larger and far more difficult management objective.

### ACKNOWLEDGMENTS

This study was funded in part by the U.S. Army Corps of Engineers (MIPR W68MD983512421) and the City of Renton. The project was administered by Merri Martz, USACOE. and Gary Schimek, City of Renton. We thank USFWS employees: H. Gearns, M. Mizell, R. Peters, D. Low, F. Mejia, and B. Missildine for their assistance with the field work. D. Seiler, WDFW, provided information on sockeye fry abundance and migration timing. R. Little, Seattle Water Department, provided information on streamflow conditions.

#### REFERENCES

- Bardonnet, A. and M. Heland. 1994. The influence of potential predators on the habitat preferenda of emerging brown trout. Journal of Fish Biology 45 (supplement A):131-142.
- Barrett, J.C., G.D. Grossman, and J. Rosenfeld. 1992. Turbidity-induced changes in reactive distance of rainbow trout. Transactions of the American Fisheries Society 121:437-443.
- Foote, C.J. and G.S. Brown. 1998. The ecological relationship between sculpins (genus *Cottus*) and beach spawning sockeye salmon (*Oncorhynchus nerka*) in Iliamna Lake, Alaska. Canadian Journal of Fisheries and Aquatic Sciences 55:1524-1533.
- Gaudin, P. and L. Caillere. 1985. Relation chabots truites: resultats obtenus en riviere experimentale. Internationale Vereinigung fur theoretische und angewandte Limnologie Verhandlungen 22:2581-2586.
- Ginetz, R.M and P.A. Larkin. 1976. Factors affecting rainbow trout (*Salmo gairdneri*) predation on migrant fry of sockeye salmon (*Oncorhynchus nerka*). Journal of the Fisheries Research Board of Canada 33:19-24.
- McDonald, J. 1960. The behaviour of Pacific salmon fry during their downstream migration to freshwater and saltwater nursery areas. Journal of the Fisheries Research Board of Canada 17:655-676.
- Phillips, R.W. and E.W. Claire. 1966. Intragravel movement of the reticulate sculpin, *Cottus perplexus*, and its potential as a predator on salmonid embryos. Transactions of the American Fisheries Society 95:210-212.
- Seiler, D. and L.E. Kishimoto. 1996. 1995 Cedar River sockeye salmon fry production evaluation. Annual report, Washington Department of Fish and Wildlife, Olympia, Washington.
- Seiler, D. and L.E. Kishimoto. 1997. 1997 Cedar River sockeye salmon fry production evaluation. Annual report, Washington Department of Fish and Wildlife, Olympia, Washington.
- Tabor, R.A., G. Brown, and V.T. Luiting. 1998a. The effect of light intensity on predation of sockeye salmon fry by prickly sculpin and torrent sculpin. Miscellaneous report. U.S. Fish and Wildlife Service, Aquatic Resource Division, Lacey, Washington.
- Tabor, R.A., J. Chan, and S. Hager. 1998b. Predation on sockeye salmon fry by cottids and other predatory fishes in the Cedar River and southern Lake Washington. Miscellaneous report. U.S. Fish and Wildlife Service, Western Washington Fishery Resource Office, Lacey, Washington.

Vinyard, G.L. and A.C. Yuan. 1996. Effects of turbidity on feeding rates of Lahontan cutthroat trout (*Oncorhynchus clarki henshawi*) and Lahontan redside shiner (*Richardsonius egregius*). Great Basin Naturalist 56:157-161.

Zar, J.H. 1984. Biostatistical analysis. Prentice-Hall, Inc., Englewood Cliffs, New Jersey.